

**Novel Thermoplastic Hydrogel Polymer Compositions for use  
in producing contact lenses and Methods of Producing said  
Compositions**

The present invention relates generally to production of thermoplastic materials which swell in water to produce hydrogels. These materials will hereafter be referred to as "thermoplastic hydrogels". They are useful as contact lenses or for use in vision correction prosthetics or as cosmetic devices. In particular, the invention relates to thermoplastic hydrogels which show improved flow characteristics.

It is already known in the art to make contact lenses using hydrogels. Generally these hydrogels do not utilise poly(ethylene glycols) but are made from the polymerisation of the single monomers HEMA, NVP or of other products of free radical polymerisation. However, these compositions generally are cross-linked and do not flow and can only be moulded by reaction injection moulding (RIM) or related "polymerisation in place" processes, which are slow and relatively expensive

1 processes which are not particularly suited to contact  
2 lens manufacture.

3  
4 Attempts have been reported (US Patent number 4,644,033)  
5 to incorporate the highly desirable properties of  
6 poly(ethylene oxide) molecular chains into crosslinked  
7 polyurethane materials for use, inter alia, in contact  
8 lenses. It was found that such preparation procedures in  
9 the absence of solvent produced only opaque products when  
10 swollen in water. Such opaque products cannot be used  
11 for the manufacture of contact lenses which demand  
12 clarity. It was found that clear urethane cross-linked  
13 polyethylene glycol products could be produced in the  
14 presence of dry organic solvent. This adds the necessity  
15 of solvent removal and raises questions of residual  
16 solvent toxicity to the cost of manufacture.

17  
18 Also, existing reaction injection moulding techniques  
19 utilise free radical initiation or irradiation cure that  
20 produces radicals. These radicals initiate a  
21 peroxidation chain process, which leads ultimately to  
22 damage of PEO based polymers in storage for use which  
23 gives a short life to contact lenses produced from them.  
24 There are also problems with bio-compatibility of  
25 reaction injection moulded hydrogels which again is not  
26 ideal for the manufacture of contact lenses where bio-  
27 compatibility is importantant.

28  
29 Additionally, the current cross linked polymer hydrogels  
30 often have a very poor resistance to crack initiation and  
31 crack propagation which again can be problematic when  
32 producing contact lenses.

33

1 It can therefore be seen that it would be beneficial to  
2 provide thermoplastic hydrogels which are capable of  
3 being generally moulded under pressure so that contact  
4 lenses can be easily and cheaply produced.

5  
6 It is an aim of the present invention to provide a  
7 thermoplastic hydrogel composition which has the ability  
8 to flow under moderate shear at particular temperatures  
9 below the polymer decomposition temperature.

10  
11 It is a further object of the present invention to  
12 provide a thermoplastic hydrogel composition which can be  
13 injection or compression moulded.

14  
15 It is a further object of the present invention to  
16 provide a solvent soluble composition.

17  
18 Another object of the present invention is to provide a  
19 thermoplastic hydrogel composition which is highly bio  
20 compatible.

21  
22 A yet further object of the present invention is to  
23 provide thermoplastic hydrogels which have a high level  
24 of water swelling properties after moulding and swelling  
25 with water.

26  
27 It is a further object of the present invention to  
28 provide thermoplastic hydrogels which can cover a range  
29 of degrees of water swelling.

30  
31 It is a yet further object of the present invention to  
32 provide thermoplastic hydrogels that by design and choice  
33 are either clear or opaque to visible light.

1  
2 According to a first aspect of the present invention,  
3 there is provided a method of producing thermoplastic  
4 hydrogels for use in producing contact lenses, comprising  
5 the steps of reacting one or more from the list;

6 polyethylene oxide,

7 polyol,

8 polyamine,

9 with a polyisocyanate and a polyfunctional amine or  
10 polyalcohol.

11  
12 Preferably the polyol is polyethylene glycol.

13  
14 Preferably, the method also comprises the step of end  
15 capping unreacted groups with a unit capable of producing  
16 hydrogen bonding,  $\pi$  bonding, ionic bonding, hydrophobic  
17 bonding and/or phase separation or forming a glassy or  
18 crystalline phase separated domain.

19  
20 Alternatively, according to a second aspect of the  
21 present invention, the method also comprises the step of  
22 end capping unreacted groups with a unit from a list of:

23 Mono-functional amine

24 Mono-functional isocyanate

25 Mono-functional anhydride

26 Mono-functional acid

27 A cyclic diacid anhydride

28 Mono-functional alcohol

29  
30 Preferably the reaction between one or more from the list

31 polyethylene oxide

32 polyol

33 polyamine

1 and a polyisocyanate is prepared using a range of NCO:OH  
2 or NCO:NH<sub>2</sub> ratios.

3  
4 Optionally a biodegradable unit may be incorporated.

5  
6 The biodegradable unit may be polycaprolactone, poly  
7 (lactic acid), poly(glycolic) acid or  
8 poly(hydroxybutyric)acid, amine or hydroxyl ended  
9 poly(amino) acids (protein or peptide analogues).

10  
11 The ratios are preferably selected such that, at complete  
12 reaction, the product does not form a macrogel.

13  
14 Preferably the first step reaction is prepared using a  
15 range of NCO:OH or NCO:NH<sub>2</sub> ratios from 2:1 to 1:2.

16  
17 Optionally where both OH and NH<sub>2</sub> groups are used within  
18 the single reaction, a range of NCO:(OH+NH<sub>2</sub>) ratios of 2:1  
19 to 1:2.

20  
21 Most preferably the first step reaction is prepared using  
22 NCO:OH or NCO:NH<sub>2</sub> ratios of 2.0:1 to 1:1.8 and 1.8:1 to  
23 1:1.8.

24  
25 Optionally the range of ratios used may be extended by  
26 the addition of monofunctional amines, alcohols or  
27 cyanates.

28  
29 Alternatively, a macrogel is prevented from forming by  
30 stopping the reaction before completion.

31

1 Preferably, the reaction is stopped by the addition of a  
2 monoamine, an amine terminated polymer, a mono-alcohol or  
3 an alcohol terminated polymer.

4  
5 Optionally, the monoamine, mono-alcohol, amine terminated  
6 polymer or alcohol terminated polymer is added when the  
7 reaction is partially complete.

8  
9 Alternatively, an amine or alcohol is admixed at the  
10 outset thus removing the possibility of gelation.

11  
12 Preferably, the amine is added in the form of amine  
13 carbonate.

14  
15 Typically, products with NCO end groups are subjected to  
16 a final curing by immersion in liquid water or steam  
17 after moulding.

18  
19 Preferably, in the second stage the unreacted groups are  
20 capped with an amine.

21  
22 Optionally, unreacted NCO groups are endcapped.

23  
24 Another option is that unreacted OH groups are endcapped.

25  
26 Preferably, terminal NCO groups are converted into a  
27 strongly hydrogen bonding urea group.

28  
29 Preferably, the unreacted groups are capped with an  
30 aliphatic amine.

31  
32 Optionally, the amine group is attached to a long linear  
33 or branched alkyl group or to an aryl- or aralkyl-amine.

1  
2 Optionally, the amine group is attached to polymers or  
3 low molecular weight pre-polymers.  
4

5 Alternatively, excess OH groups are capped with one or  
6 more molecules from the list of;  
7 mono-isocyanate ended aromatic molecules,  
8 mono-acid anhydride ended aromatic molecules,  
9 mono-isocyanate ended aliphatic molecules,  
10 mono-acid anhydride ended aliphatic molecules  
11 reaction product of a monoamine with a di(or higher)  
12 isocyanate.  
13

14 The groups used in the endcapping process allow the  
15 polymers to interact with physical or chemical cross-  
16 linking. The separate molecules or particles therefore  
17 bind to each other.  
18

19 According to the third aspect of this invention there is  
20 provided a thermoplastic hydrogel for use in producing  
21 contact lenses, prosthetic lenses or cosmetic lenses  
22 produced by the methods of the first and second aspects.  
23

24 Preferably, the hydrogel is completely polymerised under  
25 the specific conditions that are being used.  
26

27 Preferably, after polymerisation the hydrogel is heated.  
28

29 Alternatively, after polymerisation the hydrogel is  
30 immersed in water liquid or vapour.  
31

1 Optionally, the end product may be pelletised, pressed,  
2 extruded or heat, pressure, injection or compression  
3 moulded.

4  
5 Preferably, the end product incorporates an antioxidant  
6 containing two or more hydroxyl groups.

7  
8 The antioxidant may be internal or external.

9  
10 Preferably, the antioxidant is ascorbic acid.

11  
12 Alternatively, the antioxidant is 2,6-ditertiarybutyl4-  
13 hydroxanisole.

14  
15 Optionally the end product may develop opacity when  
16 swollen in water, thereby behaving as though it a  
17 contained a light scattering pigment with the appearance  
18 of the sclera.

19  
20 Optionally, the end product can incorporate dye(s).

21  
22 Optionally the end product can incorporate pigment

23  
24 Optionally the end product may be blended with a  
25 water-soluble compatible solvent or plasticiser.

26  
27 According to a fourth aspect of the present invention  
28 there is provided a contact lens, prosthetic lens or  
29 cosmetic lens produced from the hydrogel of the third  
30 aspect.



1 An example of the present invention will now be  
2 illustrated by way of example only and with reference to  
3 the following figure, in which:

4  
5 Figure 1 shows typical end groups that could be envisaged  
6 as being associated in stacks as shown.

7  
8 In the preferred embodiment, the thermoplastic materials  
9 are prepared from mixtures of di (or higher) PEG polyol  
10 with a di (or higher) polyisocyanate and/or a di (or  
11 higher) polyamine.

12  
13 First stage materials can also be made from many step-  
14 growth reactions amongst which the reaction of PEG  
15 polyols with polyacids with removal of reaction-produced  
16 water is an option. The production of first stage  
17 materials can also be guided by the art of making alkyd  
18 resins in the paint industry.

19  
20 If the product from the first stage reaction is made from  
21 a mixture of PEG diol, 1, 2, 6-hexantriol and  
22 diphenylmethane-4,4-diisocyanate, it can be prepared  
23 using a range of NCO:OH ratios from, for example, 2:1 to  
24 1:2. At the extremes of these ratios, the 2:1 will have  
25 all NCO unreacted groups and the 1:2 ratio will have all  
26 OH unreacted groups. These compositions are not able to  
27 macrogel and will contain only small proportions of  
28 modest molecular weight branched polymers. The product  
29 is a fluid and suitable for injection, extrusion or  
30 compression moulding at temperatures which are typically  
31 below 150°C, although temperatures of 200°C to 250°C can  
32 be utilised for short periods. It should be noted that  
33 the products with NCO end groups can only be moulded and

1 subjected to final curing by immersion in liquid water or  
2 steam for a suitable period.

3  
4 It is possible to use intermediate NCO:OH ratios, such as  
5 2:1 to 1:1.8 and 1.8:1 to 1:1.8 (and these ranges can be  
6 further extended by the addition of mono-functional  
7 molecules). As these still provide at complete reaction,  
8 fluid systems, which when the end groups, are NCO can be  
9 injection moulded and post-cured by water or steam  
10 immersion. However, depending on the proportion of tri  
11 or higher functional materials, ratios such as 1.6:1 to  
12 1:1.6 form macrogels at as complete a reaction as is  
13 possible with the NCO and OH groups present (and less  
14 extended ratios are possible if mono-functional amines,  
15 alcohols or cyanates are used in the first stage. The  
16 resulting products are not fuseable and are not solvent  
17 soluble). It is possible that the products may still be  
18 used for the second stage of the process, to give useful  
19 end capped products, if the reaction is stopped before it  
20 has proceeded as far as possible. This operation is less  
21 convenient and more difficult as the degree of completion  
22 of the reaction must be determined using, for example,  
23 infra-red analysis of the isocyanate absorption peak of  
24 the reaction mixture, or by the viscosity of the  
25 reaction. Therefore, it is much preferred to use the  
26 compositions which cannot macrogel, as they can be taken  
27 to completion of the first stage without fear of  
28 irreversibly solidifying the reactants.

29  
30 A preferred embodiment is that the first stage product is  
31 a heavily branched polyurethane/PEG resin. In this  
32 embodiment, the second stage is intended to convert each  
33 of the terminal groups into a strongly hydrogen bonding

1 urea group. An aliphatic amine could be used and the  
2 amine group could be attached to a short or long linear  
3 or branched (preferably linear) alkyl group, such as  
4 decyl or stearic or higher polyamines such as amine ended  
5 polyethylene, or to an aryl or aralkylamine, such as  
6 aniline, aminoanthracene or octylaniline. The  
7 combination of the urea group and the long aliphatic  
8 chain or aromatic ring will promote association and phase  
9 separation of these groups with development in the  
10 product material of toughness and strength by hydrogen  
11 bonding and hydrophobic bonding. This will be especially  
12 the case where an aromatic diisocyanate has been utilised  
13 in stage one.

14  
15 Figure 1 shows a diagram of a typical end group which  
16 could be envisaged as associating in stacks, as shown.  
17 The association of many such end groups should provide  
18 increased cohesion and strength to the product.

19  
20 Once the initial homogeneous mixing has been completed,  
21 then the still fluid mix may be poured into suitable  
22 containers, such as polypropylene moulds. The  
23 polymerisation (curing) of the finished product can then  
24 be completed. In order to provide an oxidation resistant  
25 product, it is particularly useful to incorporate a  
26 reactive antioxidant containing two or more hydroxyl  
27 groups, for example, ascorbic acid (alternatively an  
28 external anti-oxidants may be used). Alternatively the  
29 antioxidant may be added in earlier during the first  
30 stage.

31

1 The final product can be extruded or spun into film or  
2 fibre or coated onto staple or continuous preformed  
3 fibres to provide a form of product which can be  
4 knitted, braided woven or otherwise fabricated by  
5 techniques well know to those skilled in the art. The  
6 product has a number of benefits, in particular as there  
7 will be no unreacted extractable groups left in the  
8 completed product, it is particularly useful for contact  
9 lenses as it is bio-compatible. There is also the  
10 benefit that materials made from the final hydrogel  
11 product which are soft and strong would be comfortable  
12 and re-useable again something which can be particularly  
13 useful in contact lens manufacture. The final product  
14 would also have the benefit of being intrinsically  
15 rubbery in their dry state, and therefore contact lenses  
16 would not set rigid when dried out. Also, coloured dyes  
17 and pigments can be put into the final product easily,  
18 which cannot be done readily with similar cross-linked  
19 hydrogels and this could be useful when making "fashion"  
20 contact lenses, or sun protective or prosthetic contact  
21 lenses which have colours, designs or dyes with  
22 particular characteristics incorporated into them.

23

24 The product of this invention can be designed to either  
25 be clear for vision correction contact lenses or opaque  
26 for cosmetic lenses or prosthetic lenses. The general  
27 empirical rule for clear lenses is that the components  
28 should be compatible in both the reaction mixture and in  
29 the product. The well known solubility parameters  
30 available may be used as a guide to materials that will  
31 be compatible and produce clear lenses. Reaction  
32 materials having large solubility parameter differences  
33 but which provide a homogenous reaction mixture will be

likely to produce opaque white material on polymerisation. Such materials are desirable for the simulation of bright white sclera for cosmetic or prosthetic lenses. When reaction mixtures are changed systematically within a series of identical reagents in varying ratios, often both clear and opaque formulations are formed from particular ranges of compositions made from the same stock of starting materials.

It is worth noting that in many cases clear lenses occur mainly when using aromatic amines and opaque when using aliphatic amines, although this is not necessarily always the case.

#### Examples

**1. POLYMERS PREPARED BY USING THE ALIPHATIC AMINE ETHYLENEDIAMINE (EDA) AND ALIPHATIC ISOCYANATE DICYCLOHEXYLMETHANE-4,4'-DIISOCYANATE (DesmodurW). 1,2,6-HEXANE TRIOL (HT) WAS ALSO USED. THE POLY(ETHYLENE GLYCOL) (PEG) HAD A MEASURED NUMBER AVERAGE MOLECULAR WEIGHT OF 3130 AND THE POLY(PROPYLENE GLYCOL) PPG A VALUE OF 425.**

The following compositions were prepared where the symbols carry the usual names.

(a) PUU3130CX (0.5HT) (0.5EDA)

	<u>mol</u>	<u>intended wt</u>	<u>actual wt</u>
		<u>used (g)</u>	<u>used (g)</u>
PEG 3130	(1)	5.00	5.00
PPG 425	(15)	10.1837	10.188

1	HT	(0.5)	0.1071	0.1071
2	EDA	(0.5)	0.048g	0.050
3	DesmodurW	(18.11)	7.5950g	7.595
4	FeCl <sub>3</sub>	0.02 wt%	4.58mg	4mg

5

6 **Procedure**

7

8 The following method of preparation was used for all of  
9 the examples that follow. All of the reaction components  
10 were either dry as used or else they were dried (i.e.  
11 the PEO AND PPG) using a "Rotavap" rotating heated vacuum  
12 drier. The dry PEG , PPG and HT were placed in a beaker  
13 and heated to 95C and mixed thoroughly with the aid of a  
14 glass rod. The anhydrous ferric chloride catalyst was then  
15 blended in small increments at a time with stirring  
16 ensuring that each small addition was dissolved before  
17 the next was added. When an amine was used it was added  
18 and blended in a similar fashion. Finally the DesmodurW  
19 diisocyanate was added as rapidly as possible with  
20 stirring and the reaction allowed to proceed at 95C.

21

22 Cured for 20 hours at 95°C. The product was solid at room  
23 temperature and thermoplastic at elevated temperatures.  
24 It formed contact lenses, by the usual method of pressing  
25 between polypropylene moulds, which were readily  
26 demoulded when cold.

27

28 The lens was initially clear but became slightly hazy in  
29 water.

30

31 The polymer swelled to high degree in tetrahydrofuran but  
32 would not dissolve.

33

1 (b) PUU3130DX (0.5HT (0.5EDA)

2		<u>mol</u>	<u>intended wt.</u>	<u>actual wt</u>
3			<u>used (g)</u>	<u>used (g)</u>
4	PEG 3130	(1)	5.00	5.124
5	PPG 425	(20)	13.5782	13.580
6	HT	(0.5)	0.10717	0.1071
7	EDA	(0.5)	0.0480	0.059
8	DesmodurW	(23.3625)	9.7965	9.796
9	FeCl <sub>3</sub>	0.02 wt%	5.7mg	6mg

10

11 Procedure

12

13 Synthesised in the manner presented above. The product  
14 was a soft solid which was thermoplastic. It was a  
15 suitable material for further modification by reaction  
16 with amine or hydroxyl-containing modifiers as is  
17 illustrated for a related composition in the following  
18 example in which the proportion of isocyanate-containing  
19 component DesmodurW is increased.

20

21 The compression method afforded lenses very easily from  
22 this product without further reaction but the product was  
23 very sticky and did not demould in dry state. The lens  
24 with mould was immersed in water over weekend after which  
25 time the lens had swollen off it's support. It was  
26 soluble in THF.

27

28

29 **2. A STAGE1 POLYMER WITH EXCESS OF ALIPHATIC ISOCYANATE**  
30 **AND A LINEAR ALIPHATIC AMINE (0.75 EDA)**

31

32 PUU3130CX(0.5HT) (0.75 EDA) with excess of DesmodurW

33

	<u>mol</u>	<u>intended wt.</u>	<u>actual wt.</u>
		<u>Used (g)</u>	<u>used (g)</u>
3	PEG 3130	(1)	5.00
4	PPG 425	(15)	10.1837
5	HT	(0.5)	0.1071
6	EDA	(0.75)	0.071
7	DesmodurW	(44.0)	18.450
8	FeCl <sub>3</sub>	0.02 wt%	4.58mg
9			5mg

### Procedure

The usual method. The product solidified on cooling but melts when hot.

This product produced lens-shape by the usual method. The product was immersed in water when it fragmented. White sections of polymer were obtained in the lens mould. This material was soluble in methanol and precipitated when a little water were added. The product was also soluble in tetrahydrofuran. It is not suitable for moulding into lenses but is used here to exemplify the ready formation of end-capped modified thermoplastic polymers using the following end group modifiers by:

2.a Reaction with benzylamine in the absence of solvent.

2.b Reaction with butylamine in the absence of solvent

2.c Reaction with dibutylamine in the absence of solvent

Those expert in the synthesis of polymers would readily see how to extend this procedure to many other simple amine or hydroxyl-containing molecules and to end-capping



1 with many amine and hydroxyl ended low-molecular weight  
2 polymers.

3

#### 4 **2.a Reaction with Benzylamine**

5

6 Wt of the prepolymer with excess isocyanate = 4.275g

7 Wt of the benzylamine = 1.00g

8

#### 9 **Procedure**

10

11 Both materials were mixed and allowed to react at 95°C for  
12 half an hour. The materials were in a round bottom flask  
13 that was rotated using a rotary evaporator while immersed  
14 in an oil bath at 95°C.

15

16 The product was thermoplastic and fluid and could be  
17 readily moulded into a lens that appeared optically  
18 transparent though it was fragile and broke when attempts  
19 were made to detach it from the mould.

20

#### 21 **2.b Reaction with Butylamine**

22

23 Weight of the prepolymer = 4.278g

24 Weight of the butylamine = 1.380g

25

#### 26 **Procedure**

27

28 The reaction was carried out in a beaker placed in an  
29 oven at 95°C with stirring manually, using a glass rod.  
30 The polymerising mixture was cured for 2 hours at 95°C.  
31 The product was a brittle, hard, thermoplastic which  
32 forms a clear lens.

33

**2.c Reaction with Dibutylamine**

Weight of the stagel polymer = 4.275g

Weight of the benzylamine = 1.380g

The procedure used was the same as described in (2.b).

The product was a sticky, thermoplastic which can be moulded into a lens easily but is physically rather weak after immersion in water.

**3. PREPOLYMER WITH EXCESS OF OH GROUPS CONTAINING EXCESS HYDROXYL AND UREA UNITS FORMED USING AN AROMATIC AMINE DIPHENYLMETHANE-4,4'-DIISOCYANATE (DPDA).****PUU3130CX(0.5HT) with excess of alcohol groups**

	<u>mol</u>	<u>intended wt</u>	<u>actual wt</u>
		<u>used (g)</u>	<u>used (g)</u>
PEG 3130	(1)	10.00 g	10.01
PPG 425	(15)	20.3674	20.376
HT	(0.5)	0.2143	0.214
EDA	(0.5)	0.3167	0.317
DPDA	(10.25)	8.5962	8.63 g
FeCl <sub>3</sub>	0.02 wt%	7.96 mg	8.0 mg

The prepolymer was prepared as above and remained liquid after 5 hours of reaction at 95°C. The mixture could not be gelled and demonstrates the ability of compositions having a suitable excess of one of the reacting groups to provide a stagel polymer without the possibility of gelling in the reaction vessel. On cooling the material solidifies but melts again when heated. It forms a

useful basis for either end-capping with desired materials or for preparing reactive mixtures which can be formed into lens shapes and subsequently crosslinked by heating. Because of its fast rate of reaction the aliphatic diisocyanate DPDA is a very suitable crosslinking agent.

This prepolymer was used for the following curing reaction:

#### The Prepolymer and Desmodur W

Weight of the stage 1 polymer with excess of alcoholic groups =10.0 g

DesmodurW added to the same beaker =1.467 g

Mixed well. The resulting very fluid material was poured into a polypropylene tube and cured for 4 hours at 95°C. The polymer gelled sometime within 2 hours and on cooling provided a strong crosslinked product. This would clearly have been able to be moulded and formed into crosslinked lenses before the second stage curing.

#### Incorporation of antioxidant butylated hydroxyl anisole (BHA) and using diphenylmethane-4,4'-diamine (DPDA) PUU5950 BX (0.75 HT)

	<u>mol</u>	<u>intended wt.</u>	<u>Actual wt</u>
		<u>used (g)</u>	<u>used (g)</u>
PEG 5950	(1)	10	10.00
HT	(0.75)	0.1691	0.169
PPG 425	(10)	7.1428	7.147
DesmodurW	(13.2562)	5.8483	8.63 g

1	BHA	(0.03% by	3 mg	3 mg
2		wt of PEG)		
3	DPDA	(0.5)	0.1666	0.166
4	FeCl <sub>3</sub>	0.02 wt%	4.66 mg	4.0 mg

5

6 When BHA added to the reaction there was a very slight  
 7 darkening in the colour. change in colour. The reaction  
 8 product was fluid and could be moulded into clear contact  
 9 lenses.

10

# Procedure

12

13 HT and PPG, FeCl<sub>3</sub> and DPDA, BHA and D were mixed in this  
 14 order and allowed to cure in polypropylene test-tube.

15

16		<u>mol</u>	<u>intended wt</u>	<u>actual wt</u>
17			<u>used (g)</u>	<u>used (g)</u>

18

19	PEG 5950	(1)	10	10.02
20	HT	(0.75)	0.1691	0.171
21	PPG 425	(10)	7.1428	7.147
22	DesmodurW	(13.2562)	5.8483	8.63 g
23	BHA	.3% by wt.	0.3000 mg	0.305 mg
24		of PEG)		
25	DPDA	(0.5)	0.1666	0.166
26	FeCl <sub>3</sub>	0.02 wt%	4.66 mg	6.0 mg

27

28 In the case of the very high 3% level of BHA the reaction  
 29 became immediately very dark but returned to slightly  
 30 darker yellow than expected without BHA when PEG was  
 31 added and mixed. No other visual effect was observed and  
 32 the product set solid when cold and became fluid and

1 mouldable when hot when it could be moulded readily into  
2 transparent lenses

3

4 These results show that the antioxidant BHA can be  
5 incorporated into the stagel reaction.

6

7

8 **4. THERMOPLASTIC HYDROGELS SUITABLE FOR USE IN CLEAR**  
9 **VISION CORRECTION CONTACT LENSES.**

10

11 Thermo plastic hydrogelcompositions were made from  
12 poly(ethylene glycol), poly(propylene glycol), 1,2,6-  
13 hexane triol, dicyclohexylmethane-4,4'-diisocyanate and  
14 diphenylmethane-4,4'-diamine(DPDA). The overall  
15 composition has a functionality of >2.

16 Three batches of poly(urethane urea) denoted PUU polymers  
17 coded PUU 5950 BX (0.5 HT), PUU 5950 BX (0.6 HT), and PUU  
18 5950 BX (0.75 HT) were prepared by a single step bulk  
19 polymerisation method described below. The molar  
20 compositions and the weight compositions are given in the  
21 next two tables below.

22

23 **Chemical compositions PUU polymers**

Polymer unit denoted as	SOFT BLOCKS		HARD BLOCKS		TRIOL
	PEG	PPG 425	DPDA	Desmodur W	HT
	moles	(moles)	(moles )	(moles)	(mole s)
PUU5950 BX (0.5HT) Batch 1,2,3	1	10	0.5	12.8625	0.5
PUU5950 BX (0.6HT) Batch 1,2,3	1	10	0.5	13.02	0.6

PUU5950 BX (0.75HT)	1	10	0.5	13.2562	0.75
Batch 1,2,3					

1  
2 Ferric chloride catalyst was used as 0.02 wt% of the  
3 reactants  
4 DesmodurW was used as 5 mol% in excess of stoichiometric  
5 quantity  
6 The appropriate quantities of hexane triol (HT) and  
7 dehydrated PPG 425 weighed into a beaker to which the  
8 calculated quantity of ferric chloride catalyst was  
9 added. The beaker was then placed in the oven at 95 C.  
10 Within ~15 minutes the catalyst dissolved assisted by  
11 occasional stirring. The DPDA was then added, mixed and  
12 left in the oven. Once the DPDA had dissolved the  
13 dehydrated molten PEG was added, mixed thoroughly and  
14 left in the oven for few minutes. Finally, the required  
15 amount of Desmodur W (dicyclohexylmethane-4,4'-  
16 diisocyanate) was directly weighed into the beaker  
17 containing the other reactants, mixed and left in the  
18 oven with occasional stirring for 15 minutes. This was  
19 then poured into preheated polypropylene moulds and  
20 placed in the oven at 95 deg C to cure over 22 hours.  
21 After this period the oven was switched off, the product  
22 was allowed to cool and readily demoulded after quenching  
23 in liquid nitrogen.

#### 24 Weights of reactants used

25

Polymer denoted as	SOFT BLOCK		HARD BLOCK		Triol
	PEG (g)	PPG 425 (g)	DPDA (g)	Desmodur W (g)	HT (g)
PUU5950BX (0.5HT)	10	7.1428	0.166	5.6746	0.1127

Batch1,2,3			6		
PUU5950BX (0.6HT)	10	7.1428	0.166	5.7441	0.1353
Batch1,2,3			6		
PUU5950 BX (0.75HT)	10	7.1428	0.166	5.8483	0.1691
Batch1,2,3			6		

Ferric chloride was used as 0.02 wt% of the reactants  
DesmodurW was used as 5 mol% in excess of stoichiometric  
quantity  
Actual amounts of the materials used were kept close to  
the calculated values

#### **Swelling test.**

Slices from polymer billets were cut and three slices of  
essentially identical thickness were allowed to swell to  
equilibrium in water at ambient temperature. The swelling  
(%) calculated by the equation: % swelling = Weight of  
the swollen slice - weight of the dry slice/weight of the  
swollen slice. The three test results were averaged.

#### **Test of thermoplasticity.**

A small disk of the thermoplastic hydrogel was placed  
between two polypropylene moulds which when compressed  
formed a prescription contact lens shape between their  
faces. The disk was placed into the female section and  
the male half of the mould was placed on top. After 10  
minutes heating at 95C the ability of the test  
thermoplastic hydrogel composition to flow and form a  
contact lens when cooled to room temperature was  
evaluated under the pressure between the thumb and  
forefinger. The mould was cooled and the solid moulded

1 contact lens removed using forceps and then made  
 2 available for testing.  
 3  
 4 Average swelling of PUU polymers in water at ambient  
 5 temperature.  
 6

Polymer composition	Swelling data (pph)	Swelling data (%)	Average Swelling (%)
PUU5950BX (0.5HT) Batch 1	253.6	72	
PUU5950BX (0.5HT) Batch 2	253.7	72	
PUU5950BX (0.5HT) Batch 3	244.8	71	72

PUU5950BX (0.6HT) Batch 1	246.6	71	
PUU5950BX (0.6HT) Batch 2	229.9	70	
PUU5950BX (0.6HT) Batch 3	279.7	74	71

PUU5950BX (0.75HT) Batch 1	224.5	69	
PUU5950BX (0.75HT) Batch 2	239.3	70	
PUU5950BX (0.75HT) Batch 3	222.7	69	69

#### 10 Swelling test results

11  
 12 The results from the swelling tests in water at ambient  
 13 temperature are summarised in Table 3. Only a small  
 14 variation in the swelling values was seen in the polymers



that contained HT (see Table 3) in spite of the significant change in the amount of the triol used. The visual appearance of the swollen polymers also varied. It was observed that the PUU 5950 BX (0.5 HT) polymer occasionally afforded "frostiness" possibly due to micro stress cracking in the water- swollen state. Polymer PUU 5950 BX (0.6 HT) with slightly increased HT from 0.5 molar to 0.6 molar showed the effect in an occasional batch. However such "frostiness" in PUU 5950 BX(0.75HT) was not observed at all. The lenses produced were transparent and the obtained degree of swelling of 69% is a very useful figure for contact lenses.

Some selected results from GPC analysis of PUU polymers

Polymer	$M_n$	$M_w$	$M_w/M_n$
PUU5950BX (0.5HT) Batch 1	$6.603 \times 10^3$	$1.674 \times 10^4$	$2.535 \pm 0.044$
PUU5950BX (0.5HT) Batch 2	$6.399 \times 10^3$	$1.456 \times 10^4$	$2.275 \pm 0.038$
PUU5950BX (0.5HT) Batch 3	$6.049 \times 10^3$	$1.349 \times 10^4$	$2.231 \pm 0.059$

The following conclusions can be drawn from the above

- All polymer compositions investigated were thermoplastic and afforded contact lenses when subjected to the compression technique.

- 1     ▪ The chemical structure of all the polymer  
2       compositions were shown to be similar by the FTIR  
3       analysis and reproducible within three batches of a  
4       given polymer composition.
- 5
- 6     ▪ GPC analysis Table 4 confirmed good reproducibility  
7       among three batches of a given polymer composition.  
8       The polydispersity values of all the polymers were  
9       from 2.2-2.6 . These values are quite broad but  
10      consistent with that to be expected from a step-  
11      growth polymerisation. The  $M_w$  and  $M_n$  values within  
12      three batches of a given polymer composition were  
13      quite similar - a desired result and indicates a  
14      good reproducibility.
- 15
- 16    ▪ FTIR analysis clearly indicated that free primary  
17      amine of DPDA after polymerisation has disappeared  
18      and been converted to secondary amine to form a  
19      urethane/urea group of the polymer structure.

## 20

### 21   **5. PREPARATION OF THERMOPLASTIC HYDROGELS FROM A** 22   **POLYURETHANE WITHOUT THE USE OF A DIAMINE AS A COMPONENT** 23   **OF THE STAGE 1 COPOLYMER**

## 24

25   The polymers were made according to a closely similar to  
26   the procedure described previously.above. The reactants  
27   were poly(ethylene glycol) described by the supplier as  
28   PEG6000 and meaning a PEG having a number average  
29   molecular weight close to 6000. 1,2,6-hexanetriol, and  
30   dicyclohexylmethane-4,4'-diisocyanate (DesmodurW) and  
31   using anhydrous ferric chloride (0.2mg per g. of  
32   reactants) as the catalyst. The molar proportions used  
33   are given in Table 4 below. Other compositions made

1 nearer to stoichiometry of the hydroxyl and isocyanate  
2 groups crosslinked during the curing reaction so at  
3 complete reaction could not provide thermoplastic  
4 hydrogels. They would have done so if the reactions had  
5 been terminated prior to complete reaction.

Preparation number	PEG6000	1,2,6- HEXANETRIOL	Desmodur W
1	1 MOLE	1 MOLE	3.75
2	1 MOLE	1 MOLE	5.0

7  
8 After four hours cure at 90C the products were cooled  
9 demoulded and stored in sealed bags away from air and  
10 light. A few of the samples were converted into thin  
11 slices and sample slices were evaluated for their  
12 ability to thermoform in a "Rosslyn" heat press. At  
13 115C the slices became very fluid and could be pressed  
14 into thin films. These became solid at 110C and formed  
15 solid pliable hydrogel films.

16  
17 Cut film samples were allowed to swell in water to  
18 equilibrium when they became clear transparent gels.  
19 They were insoluble in water but swelled to a high  
20 degree as given in the table below.

Sample	Dry weight of slice in g.	Swollen weight of slice	% equivalent of isocyanate in the preparation
1	.730	3.845	1.5
2	.223	2.282	2.0

1  
2 Sample 1 was completely soluble in methanol demonstrating  
3 that it was not a crosslinked gel before contact with  
4 water when the residual isocyanate groups would have been  
5 converted to urea crosslinks.

6  
7 It can be seen that the embodiments disclosed are both or  
8 merely exemplary of the present invention, which may be  
9 embodied in many different forms. Therefore, details  
10 disclosed herein are not to be interpreted as limiting,  
11 but merely as a basis for the claims and for teaching one  
12 skilled in art as to the various uses of the present  
13 invention in any appropriate matter. In particular, it  
14 should be noted that a wide variety of changes can be  
15 made in this process.

16  
17 For example, pre-polymers with excess OH can be capped  
18 with a mono-isocyanate ended aromatic or aliphatic  
19 molecule or with a reaction product of a mono-amine with  
20 di or higher isocyanate. The low molecular weight amine  
21 could be replaced with a low molecular weight polymeric  
22 amine, such as low  $M_n$  primary and secondary amine ended  
23 nylon polyamide) or polypropylene oxide, poly(butanediol)  
24 or low molecular weight polymers producing glassy domains  
25 such as end-capped polystyrenes or amine end-capped  
26 hydrophobic and crystalline domain forms such as  
27 poly(ethylene) units. The reaction can be between such  
28 amine ended PEGs (poly(ethylene glycols)) and PPGs  
29 (poly(propylene glycols)) and di or higher amines and di  
30 or higher isocyanates, but done in solvents to allow  
31 suitable reduced viscosity to be obtained. Also, to slow  
32 down the amine reaction, the amine can be added at the

1   outset as the carbonate version of amine carbonate,  
2   resulting from the reaction of amine and carbon dioxide.

3

4   Also, stage one hydroxlic excess polymers could be  
5   reacted with a phase separating polymer end capped with  
6   an anhydride group.

7

8   Finally, it should be noted that this end capping process  
9   could be applied to a wide variety of polymers, such as  
10  polyesters, nylons, polyurethanes, polyureas, polyethers,  
11  polyolefins, polyvinyls and poly(meth)acrylates.